Effects of Well Withdrawal Impacts on Souhegan River Streamflow

Introduction

On a watershed scale, surface and ground waters generally flow from regions of high elevation to low elevation. When water is diverted from either surface water or groundwater, it is diverted from the watershed-scale flow path. A surface water diversion results in a direct reduction to stream flow. A groundwater diversion may result in a reduction to stream flow and/or in a reduction of the groundwater flowing out of the watershed. The real fate of diverted groundwater is unknown without detailed investigation: that is, prior to groundwater being pumped out of a well, where it was originally going (to the stream or to deeper ground water, or flowing parallel to the stream in riverbed sediments, etc.) is unknown. Ground water supply wells in proximity to surface water bodies have the potential to draw water directly from the surface water body into the well. This is known as induced infiltration or induced recharge. Induced recharge constitutes as a direct withdrawal from surface water that is masked as a withdrawal from an aquifer.

Simply stated, instream flow is the water needed in the stream that will support aquatic habitat and resources. When the stream flow falls below the identified instream flow value, habitat and resources are stressed. One way of relieving this stress is to get more water into the stream. In the development of management strategies to support instream flows, all diversions need to be identified: their magnitude, timing, and duration. Induced recharge is one such diversion, since this is water that would have been flowing in the stream had it not been pumped. The focus of this task was to delineate and quantify induced recharge in the Souhegan River designated reach and its tributaries.

Methodology

The database of Affected Water Users (AWUs) was obtained from NH DES. This database (Table 1) includes those water users that are required (any use from a single location that exceeds 20,000 gallons per day averaged over any 7-day period or exceeds a total of 600,000 gallons during any 30-day period) to report the water use (withdrawal, diversion, instream, transfer, return flow). The reported monthly flows for each user were available back into the late 1980's.

For this task, only the ground water users were studied: their average and maximum uses were computed from the historic data. The ground water users are a subset of the entities listed in Table 1. Additionally in the NH DES data base were the distances to the river edge from each well. These distances were field verified by global positioning system in March, 2005 (accuracy of +/- 17 feet). Of 11 existing ground water users, there are 20 wells for the induced recharge investigation. No well head delineation or protection studies have been performed for these wells or registered water users.

Table 1. Registered Water Users Along the Souhegan River Designated Reach (many possess multiple locations and types of water use).

Name
PENNICHUCK WATER WORKS
GREENVILLE TOWN
WILTON WATER WORKS
GREENVILLE WWTF
MILFORD WWTF
MILFORD WATER WORKS
AMHERST COUNTRY CLUB
BUCKMEADOW GOLF CLUB
NH FISH & GAME
GREENWOOD ALDEN T
PIKE INDUSTRIES INC
NORTHEAST HYDRODEVEL CORP
PETER DE BRUYN KOPS
SOUHEGAN WOODS GOLF CLUB
MONADNOCK MOUNTAIN SPRING
PONEMAH GREEN GOLF COURSE
PENNICHUCK WATER WORKS
PILGRIM FOODS

To estimate induced recharge effects, an analytical, office technique was first employed (McWhorter and Sunada, 1977). Equation 1 describes the relationship between well discharge and the distance downgradient to the stagnation point (location in which water closer to the well flows to the well and farther from this point ground water flows away from the well – see Figure 1).

$$x_s = \frac{Q}{2\pi Ti}$$ Equation 1

where: x_s = distance from the well to the downgradient stagnation point (feet)
    Q = well discharge (cubic feet per day)
    T = formation (aquifer) transmissivity (square feet per day)
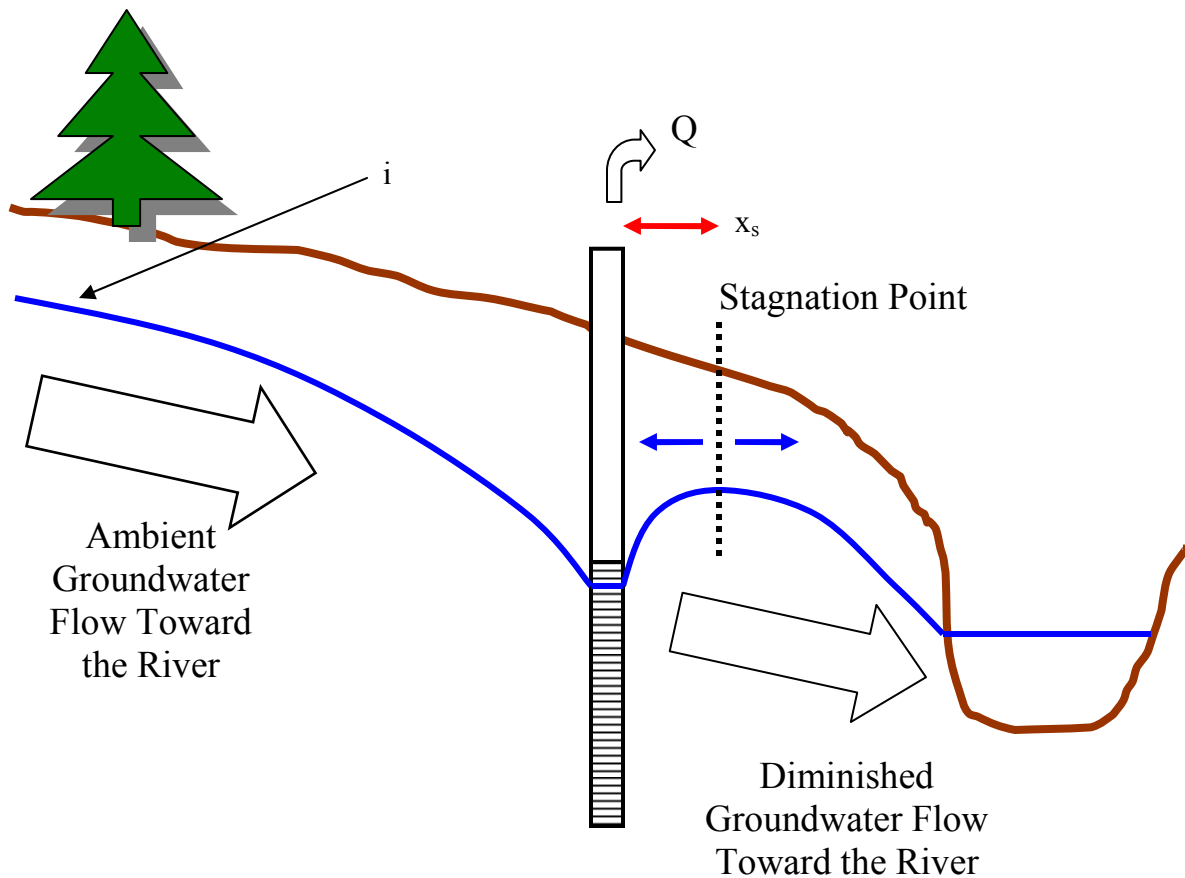   i = ground water gradient (slope) (dimensionless).

Figure 1. Definition sketch for induced recharge (see Equation 1 for details).

For this analytical treatment, the stagnation distance (x_s) was computed for each well. If it exceeded the physical distance between the real well and the nearest point to the Souhegan River, then this well was then numerically determined to be creating induced recharge. To compute how much induced recharge was occurring, the actual distance between well and river was used in Equation 1 in order to calculate the flow for that stagnation distance.

Fortunately the aquifer data (T, i) used in Equation 1 were available in the USGS aquifer publications (Toppin, 1987, Ayotte and Toppin, 1995).

As a check on this analytical methodology, two other methods were employed. The first was another office method: the US EPA Well Head Protection Analysis computer model (WHPA). The second method was a field method: miniature piezometers. WHPA uses the same input data as Equation 1. The miniature piezometers are small diameter wells that are installed in the riverbed. Without pumping, the water level in the miniature piezometer would normally be located equal or higher than the water level in the river. In locations of induced recharge, the water level in the miniature piezometers is located below the water level in the river (indicating that water is flowing from the river down into the riverbed, assumed to then flow to the well). Miniature piezometers were installed in July, 2005 and read at various times during July and August, 2005.

Results

The results of the induced recharge calculations may be found in Table 2. Eight of the reported on wells reported no use in the past five years or longer. In these cases, the wells were listed in Table 2, but no induced recharge calculations were performed since Equation 1 computes a stagnation distance of zero for a flow of zero. In Table 2, column 2 is the measured distance between each well and its nearest distance to the Souhegan River. Columns 7 and 9 depict the computed stagnation distances for the maximum and average well discharges (columns 6 and 8), respectively. When the computed stagnation point distance (columns 7 and 9) exceed the actual distance (column 2) induced recharge occurs. The wells creating induced recharge have their stagnation distances in columns 7 and 9 emboldened and in an aqua color. The well flow that created the induced recharge (columns 6 and 8) is in red. For these same wells, column 10 reports the well flow rate for the stagnation distance of column 2. The difference between this flow rate and the average well flow rate (column 8) may be found in column 11. Column 11 is therefore the reduction in the well flow rate in which induced recharge would cease. It should be underscored that these are numerical estimates of induced recharge. The WHPA model corroborated these estimates, which is no surprise since it is based on steady state ground water flow theory much the same as Equation 1.

Wells I, Q, and T exhibited computed induced recharge. These wells, and wells B and L, were studied further with the miniature piezometers. Many registered water users who employ ground water wells utilize more than one well. In Table 2, Wells I and T belong to the same registered user and are close to each other. Similarly, Wells P and Q belong to one registered user and wells B and L belong to another registered user. One miniature piezometer was set in the Souhegan River at the location of the well exhibiting induced recharge from the numerical methods. Miniature piezometers were then set at 100-foot intervals, upstream and downstream of this first piezometer until induced recharge was not exhibited in the miniature piezometers. In the case of well I (and it's pair well T), ambient groundwater gradients were not observed until 400 feet upstream and 800 feet downstream. Downward vertical ground water gradients in this stretch of the Souhegan River bed sediments ranged from almost 2.0 to the ambient level of almost zero. Comparing these vertical gradients to the horizontal gradients in Table 2 (column 4), indicates that the vertical gradients are two orders of magnitude larger than the horizontal gradients: very strong evidence of induced recharge.

For well Q, the miniature piezometers indicated induced recharge 300 feet upstream and 900 feet downstream. The vertical gradient peaked at 1.0, across from well Q, and gradually reduced back to ambient levels when moving away from the well (upstream or downstream).

Wells B and L were not computed to be inducing recharge. The miniature piezometer data corroborated the numerical estimates. The field data displayed a range of vertical gradients of 0.005 (downward) to 0.067 (upward). In general, these measured vertical gradients were in the expected range of ambient fluctuations and demonstrated upwards vertical flow (river gaining water). The few values in which a miniature piezometer indicated a downward gradient near to these wells, were well within the measurement accuracy of the miniature piezometers.

Table 2. Results of Induced Recharge Calculations

1 Well ID	2 Distance From Well to River (ft)	3 Land Slope	4 Groundwater Slope	5 Transmissivity (sq. ft./day)	6 Maximum Reported Well Discharge (1,000 gal/day)	7 Maximum Discharge Stagnation Distance (ft)	8 2000-2004 Reported Average Well Discharge (1,000 gal/day)	9 Average Discharge Stagnation Distance (ft)	10 Flow to Achieve Stagnation at River (1,000 gal/day)	11 Possible Average Flow Reduction (1,000 gal/day)
A	-	0.037	0.05	6,000	0	0.0	0	0.0	-	
B	84	0.031	0.016	3,000	31.0	13.7	20.0	8.9	189	
C	529	0.036	0.02	2,000	62.0	33.0	39.8	21.2	994	
D	110	0.01	0.01	8,000	0	0.0	0	0.0	414	
E	99	0.019	0.0133	2,000	111	88.8	41.5	33.2	124	
F	75	0.055	0.009	1,000	20.8	49.2	10.6	25.1	32	
G	994				0	0.0	0	0.0	-	
H	306				0	0.0	0	0.0	-	
I	273	0.006	0.0114	8,000	2139	499.0	1701	396.9	1,170	531
J	140	0.006	0.011	1,000	0	0.0	0	0.0	72	
K	100					-		-	-	
L	89	0.031	0.016	3,000	31.0	13.7	20.0	8.9	201	
M	92	0.0005	0.032	6,000	156	17.3	37.5	4.2	830	
N	849	0.013	0.02	6,000	312	55.3	96.0	17.0	4,788	
O	97	0.015	0.01	8,000	215	57.2	96.5	25.7	365	
P	213	0.015	0.02	8,000	700	93.1	470	62.5	1,602	
Q	74	0.015	0.01	8,000	700	186.2	470	125.0	278	192
R	110	0.01	0.01	8,000	0	0.0	0	0.0	414	
S	316				0	0.0	0	0.0	0	
T	668	0.0129	0.0017	8,000	1656	2590.8	851	1331.4	427	424

Conclusion

Three of the studied wells demonstrate induced recharge. The numerical technique was verified by the field technique. These three wells should be included in water management strategies that support instream flows for the Souhegan River. This does not necessarily mean that the wells will be throttled back during low flow times, only that should the reach of the Souhegan River, in which these wells are located, fall below the recommended instream flow value, these wells be considered in the water management strategy for that reach of the river. Such a water management strategy weighs reductions in diversions against other strategies such as: additional instream water sources, scheduling of diversions, water storage, dam operations, etc.

References

Ayotte, Joseph D. and Kenneth W. Toppin, 1995, Geohydrology and Water Quality of Stratified-Drift Aquifers in the Middle Merrimack River Basin, South-Central New Hampshire, USGS WRIP 92-4192, Bow, NH.

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McWhorter, David B. and Daniel K. Sunada, 1977, Ground-Water Hydrology and Hydraulics, Water Resources Publications, Fort Collins, CO.